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RESEARCH MEMORANDUM

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THE EFFECT OF EM MANNING ON THE MATERIAL CONDITION OF THE ELECTRICAL DISTRIBUTION SYSTEM

Dean A. Follmann

0 4 MAR 1988

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This research memorandum investigates factors that affect the material condition of a ship's electrical distribution system (EDS). Deficiencies discovered by the Naval Board of Inspection and Survey (INSURV) are used as a proxy for the material condition of the EDS. Special attention is paid to the effect of ship age, ship size, and Electrician's Mate manning.

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2. This Research Memorandum investigates factors that affect the material condition of a ship's electrical distribution system (EDS). Deficiencies discovered by the Naval Board of Inspection and Survey are used as a proxy for the material condition of the EDS. Special attention is paid to the effect of ship age, ship size, and Electrician's Mate manning.

Peter Evanovich

Peter J. Evanovich
Director
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THE EFFECT OF EM MANNING ON THE MATERIAL CONDITION OF THE ELECTRICAL DISTRIBUTION SYSTEM

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ABSTRACT

This research memorandum investigates factors that affect the material condition of a ship's electrical distribution system (EDS). Deficiencies discovered by the Naval Board of Inspection and Survey (INSURV) are used as a proxy for the material condition of the EDS. Special attention is paid to the effect of ship age, ship size, and Electrician's Mate manning.

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INTRODUCTION

A ship's electrical distribution system (EDS) provides the link between the source of electrical power and the ship's electrical loads. The EDS consists of power cables, switch gear, generator sets, and other related equipment. As such, the EDS's material condition is integral to the ship's overall material condition. Unlike many components of a ship, the EDS is not upgraded or repaired during overhaul. Most of the EDS is subject to deterioration due to corrosion, which should increase directly with exposure to a corrosive environment. Also, as a ship ages, more wires are placed on wire runways to accommodate new electrical equipment. The increased density makes troubleshooting and repair more difficult. Experience of many Naval officers indicates that an older ship's EDS requires more maintenance.

The enlisted rating primarily responsible for maintenance and operation of the EDS is the Electrician's Mate (EM). EM duties include troubleshooting and repair of electric equipment. As the EDS deteriorates, the amount of troubleshooting and repair required of the EMs should increase. A straightforward question with manning implications concerns the relationship between the condition of the EDS, a ship's age, and EM manning The purpose of this study is to measure the material condition of the EDS and to investigate how it varies with a ship's age and manning. If older ships have worse EDSs than newer ships and if more EMs can offset this degradation, older ships can benefit from more EMs.

BACKGROUND AND DATA

A measure of the condition of the EDS can be derived from the Naval Board of Inspection and Survey (INSURV) inspection. Each ship in the Navy receives an inspection roughly once every three years. During these inspections, deficiencies are noted and written up by the inspectors. Each deficiency is recorded on a 2K form, the same form used for a ship's maintenance and material management (3-M) system. INSURV assigns to each deficiency a four-digit Ship Work Breakdown INSURV (SWBI) number, which identifies the "functional" area corresponding to the deficiency. Every deficiency is classified as belonging to one of four types: mission-degrading (M), safety (S), maintainability/reliability (MR), and other.

SWBIs are coded in a hierarchical fashion and deficiencies corresponding to the electric plant begin with the number 3. Table 1 lists the SWBIs corresponding to a ship's electric plant.

On most ships, EMs are entirely responsible for the systems corresponding to the 320 and 330 SWBI subgroups (power distribution and lighting), while other ratings may be partly responsible for the 310 and 340 SWBI subgroups (generation and generation support). Group 3 and 320/330 deficiencies can be used as proxies for the EDS condition, though 320/330 deficiencies may be more affected by EM manning.

Measures of EM manning are based on the Defense Manpower Data Center (DMDC) database. The personnel composition of each ship is recorded each quarter by this data. DMDC data were used to describe the quantity/quality of a ship's EM crew. The variables listed below were used as proxies for EM effectiveness:

- EM manning by paygrade
- EM manning with Navy enlisted classification codes (NECs) by paygrade
- Average months of service for EMs
- Percentage of EMs in three education/mental group categories:
  - High school graduate, mental groups 1-3U (HSGU)
  - High school graduate, mental groups 3L and below (HSGL)
  - Non-high school graduate, mental groups 1-3U (NHSGU)
- Percentage of EMs on ship both one and two quarters before the inspection
- Percentage of EMs on ship both one and three quarters before the inspection.

TABLE 1

ELECTRIC PLANT SWBIs
(SWBI GROUP 3)

SWBI subgroup	SWBI
310 (electric power generation)	311-1 generator sets, SSTG
	311-2 generator sets, SSDG
	311-3 generator sets, SSGT
	311-4 generator sets, special frequency turbine
	311-5 generator sets, CPTG
	312-1 generator sets, emergency diesel
	312-2 generator sets, emergency gas turbine
	313-1 battery and service facilities
	314-1 motor generator sets-60 HZ
	314-2 motor generator sets-400 HZ
	314-3 power conversion, special components
	314-4 power supplies, static
320 (power distribution systems)	320-1 power cable
	320-2 switchgear and panels, electric power
330 (lighting system)	330-1 lighting distribution and fixtures
340 (power generation support system)	341-1 lube oil system, SSTG
	341-2 lube oil system, CPTG
	342-1 generator support system, SSDG
	342-2 generator support system, emergency diesel
	343-1 generator support system, SSGT
	343-2 generator support system, emergency gas turbine
	343-3 generator support system, special frequency turbine

NOTES SSTG—ship service turbine generator. SSDG—ship service diesel generator. SSGT—ship service gas turbine. CPTG—coolant pump turbine generator.

The first variable gives a count of the number of EMs on a ship, the next three should reflect the experience and intelligence of EMs. Finally, the stability of the EM crew should be captured by the last two variables. Presumably, intelligent and experienced EMs are better able to accomplish their tasks, while a cohesive EM crew ought to be more efficient.

The focus of this study is on how EM manning affects the condition of the EDS. Using some of the raw measures (e.g., number of deficiencies and number of EMs) in a statistical analysis could lead to misleading results. The total number of each is tied to ship type. For example, carriers have an extensive EDS (and many deficiencies), while FFGs have few EMs and a smaller EDS (and fewer deficiencies). A simple analysis that groups all ship types together might conclude that less manning results in fewer deficiencies. If the study is restricted to one type, however, the number of inspections for any single type is too small for reliable conclusions to be drawn.

The approach of this analysis is to include most surface ships and to standardize manning and the number of deficiencies across ship types. The idea is that standardized measures of manning and deficiencies will not vary much by ship type, so including most ship types will be appropriate. Standardizing the number of deficiencies is discussed in the next section. One approach to standardizing manning is to use manning relative to a ship's requirements. This approach has been used in previous studies [1] and [2] and puts manning of different types of ships on one scale—as a percentage of requirements. EM manpower requirements for the month following mobilization (M+1) were obtained from ship manning documents (SMDs). EM manning, by paygrade, was divided by this requirement.

Another concern is how manning requirements are set. If, for example, the worst ships receive more or more competent EMs, one might find a negative association between EM manning and the EDS condition. This potential problem seems not to be too worrisome. Manning requirements are set largely by the amount of preventive maintenance, and no policy exists to send more intelligent or better-trained EMs to the worst ships.

Variables used in the study are defined below. Each measures an attribute of an individual ship. In addition to the EM- and EDS-related variables, year of the inspection and ship characteristics were included to control for, respectively, trends over time and effects of ship type.

- Variables used to measure EDS material condition (from INSURV's deficiency file)
  - NDEF—number of EDS deficiencies
  - SAFE—number of EDS safety deficiencies
  - N32 33—number of deficiencies with 32 and 33 as the first two SWBI characters (power distribution and lighting)
  - YEAR—year of the inspection.
- Variables used to measure characteristics of a ship (from the Ship Employment History and the Naval Vessel Register II)
  - AGE—number of years between the inspection date and a ship's commissioning date

- LDISP—light displacement, in tons, of a ship
- OVHL—days between the inspection date and a ship's most recent "overhaul". Overhaul was defined as the employment terms OVHL, RAH, or PSA (see [5]).

- Variables used to measure characteristics of a ship's EM crew (from the Defense Manpower Data Center and SMDs). Except for the last two variables, EM characteristics were measured for the quarter before the inspection.
  - AVGLOS—average length of service, in months, of the ship's EMs
  - E4-6—number of EMs in ratings E4-6 divided by the SMD M+1 requirements
  - E7-9—number of EMs in ratings E7-9 divided by the SMD M+1 requirements
  - HSGU—percentage of EMs with high school diplomas and in mental groups 1-3, upper
  - HSGL—percentage of EMs with high school diplomas and in mental groups 3 and below
  - NHSGU—percentage of EMs without high school diplomas and in mental groups 1-3, upper
  - PNEC—percentage of EMs that have NECs related to the EDS
  - SAME3—percentage of EMs that were on board both the quarter before the inspection and two quarters before the inspection
  - SAME6—percentage of EMs that were on board both the quarter before the inspection and three quarters before the inspection.

The ship types used in the study are: AD, AR, AS, AE, AFS, AO, AOE, AOR, CG, CGN, CV, CVN, DD, DDG, FF, FFG, LCC, LHA, LKA, LSD, and LST. Most ship types are included, however, a few special types of ships, for example, PHMs and MSOs, were excluded.

Table 2 presents summary statistics of the variables used in the study. The number of deficiencies averages about 105 per inspection, however, it ranges from 18 on a DD to 473 on a CV. Ship age and light displacement are also quite variable. On average, EMs have about 77 months of service in the Navy and almost 60 percent of the EMs are high school graduates and in the upper mental group. The minimums of E4-6, E7-9, HSGU, HSGL, NHSGU, and PNEC as a percentage of requirements (over all ships), are all zero. This does not mean that no EMs were on these ships, rather that, for example, no EMs with ratings E7-9 were on board. For example, an FF-1052 class frigate has an M+1 manning requirement of one E7-9. Occasionally, this billet was unfilled, resulting in a percent-manning requirement of zero.

TABLE 2

SUMMARY STATISTICS

Variable	Mean	Standard deviation	Minimum	Maximum	Number
NDEF	105.3	60.6	18	473	161
AGE (years)	16.9	9.3	3.7	46.3	158
LDISP (tons)	9.267	12.739	2,480	72,978	161
OVHL (days)	1,333	770	35	3,354	159
AVGLOS (months)	76.7	23.6	16	127	156
E4-6	.94	.32	.00	2.00	158
E7-9	.84	.48	.00	2.00	156
HSGU	.59	.18	.00	1.00	156
HSGL	.04	.07	.00	.50	156
NHSGU	.30	.17	00	1.00	156
PNEC	.09	.13	.00	.80	156
SAME3	.93	.10	.43	1.00	156
SAME6	.84	.14	.29	1.00	156

One other preliminary examination is to check for any trends in the variables. Only two of the variables exhibit any trend. Table 3 presents the average of these two variables by year. The average time since overhaul, and the average number of deficiencies are both increasing as a function of year of the inspection. Because of these trends, one might spuriously conclude that time since overhaul is positively related to the number of deficiencies. Both, however, may be increasing over time for independent reasons. For example, time since overhaul is probably increasing because overhauls are becoming rare - less extensive maintenance availabilities are becoming more frequent. It is necessary, therefore, to sort out the effect of the year of the inspection and the relationship between the two variables. A technique to accomplish this by "detrending" the number of deficiencies is presented in the next section.

Finally, note in table 3 that the number of observations increases over time, except for 1987 (the deficiency file stops in early 1987). This does not mean that the number of inspections is increasing, rather that the more recent INSURV deficiency files are more likely to be machine-readable. In the early 1980s, the deficiency files did not follow a standard format.

TABLE 3

THE AVERAGES OF TWO VARIABLES
BY INSPECTION YEAR

Inspection year	Days since overhaul	Number of deficiencies
83	939 (7)	69 (7)
84	1,035 (29)	92 (30)
85	1,189 (43)	105 (43)
86	1,601 (75)	114 (74)
87	402 (2)	159 (2)

NOTE: Number of observations are in parentheses.

STATISTICAL ANALYSIS

This section presents the methods used to standardize measures (NDEF, SAFE, and N32/33) of the material condition of the EDS and examines how the measures vary with EM manning. The objective of the standardization is to develop a measure that, on average, differs little across ship type.

The three possible measures, NDEF, SAFE, and N32/33 are closely related. Figures 1 and 2 present plots of NDEF versus SAFE and NDEF versus N32/33. The correlations are, respectively, .65 and .95. These figures indicate that the three measures are providing essentially the same information. Therefore, it should be sufficient to standardize just one measure, say, the total number of deficiencies. Running an analysis on all three measures would provide three similar conclusions. As these figures indicate, two CVs have a large number of deficiencies. In addition, one LPD has an extremely large number of deficiencies relative to its type average. These three ships have a marked effect on any estimated relationship between EM manning and NDEF. Because of their disproportionate effect, these observations are excluded in the subsequent analyses.

As indicated previously, the number of deficiencies should be related to ship type. Larger ships have more extensive EDSs than smaller ships and therefore should have more deficiencies. Figure 3 presents a plot of the number of deficiencies by ship type. Clearly, deficiencies differ by type. The largest ships (CVs/CVNs) exceed the average number of deficiencies, while DDs have fewer than average. If the mean number of deficiencies per ship were the same across ship type, the chance of seeing results like those shown in figure 3 would be minuscule.[1]

One way to standardize the NDEF is to find proxy variables that reflect features of a ship that are associated with the EDS and to adjust NDEF based on these proxy variables. Figures 4 and 5 plot the number of deficiencies by the age of a ship (years since commissioning) and by the light displacement of a ship. The correlations are, respectively, .26 and .67. Presumably, light displacement acts as a proxy for the size and complexity of the EDS, while ship age acts as a proxy for the deterioration associated with age. It may be that once age and weight are factored out, the adjusted number of deficiencies differ little by ship type.

Next, a tentative standardization was attempted. The number of deficiencies on a ship was modified to factor out the effects of ship age, ship weight, and year of the

[1] An F-test of the hypothesis that the mean number of deficiencies is the same over all ship types has a value of 8.84 with 21 and 137 degrees of freedom.

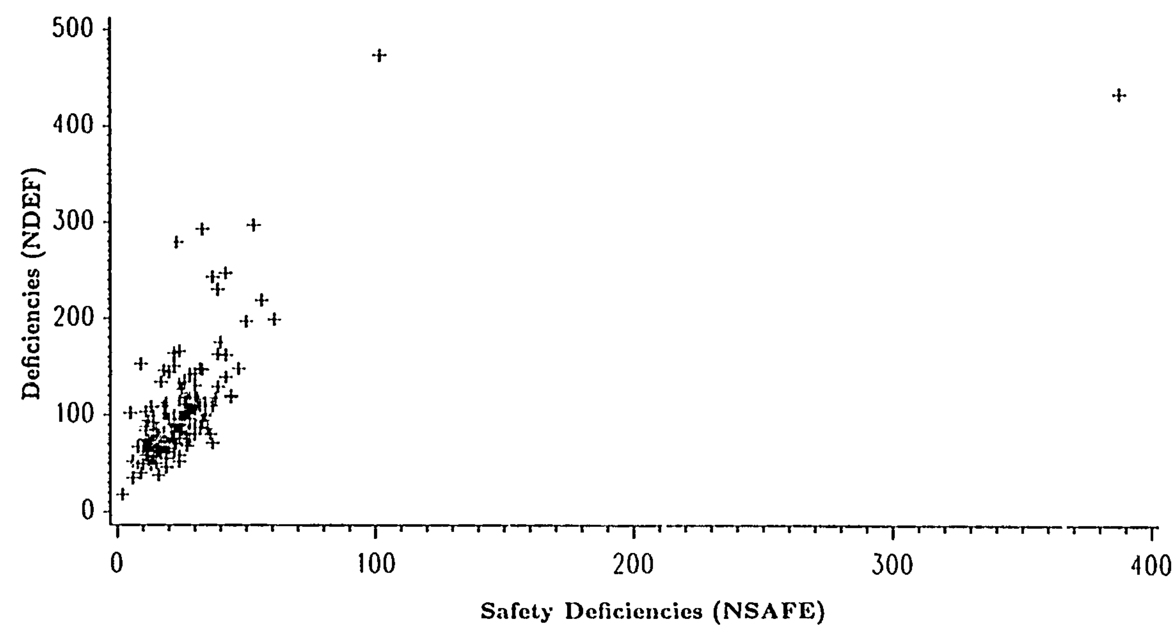

FIG. 1: NUMBER OF DEFICIENCIES BY NUMBER OF SAFETY DEFICIENCIES

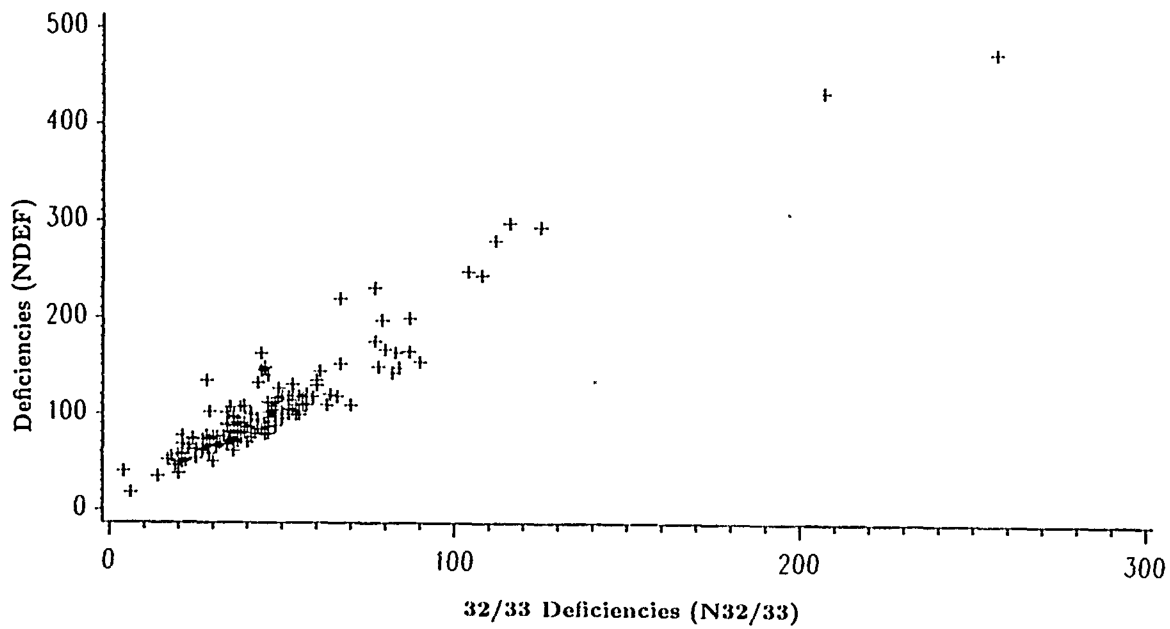

FIG. 2: NUMBER OF DEFICIENCIES BY NUMBER OF 32/33 DEFICIENCIES

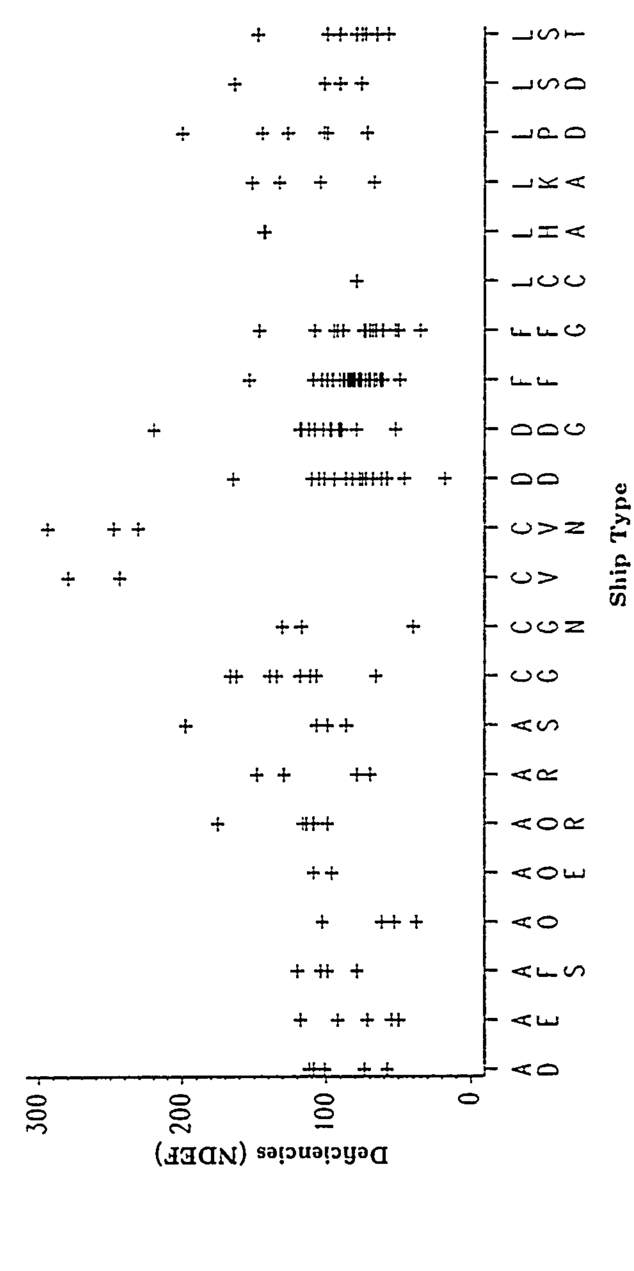

FIG. 3: NUMBER OF DEFICIENCIES BY SHIP TYPE

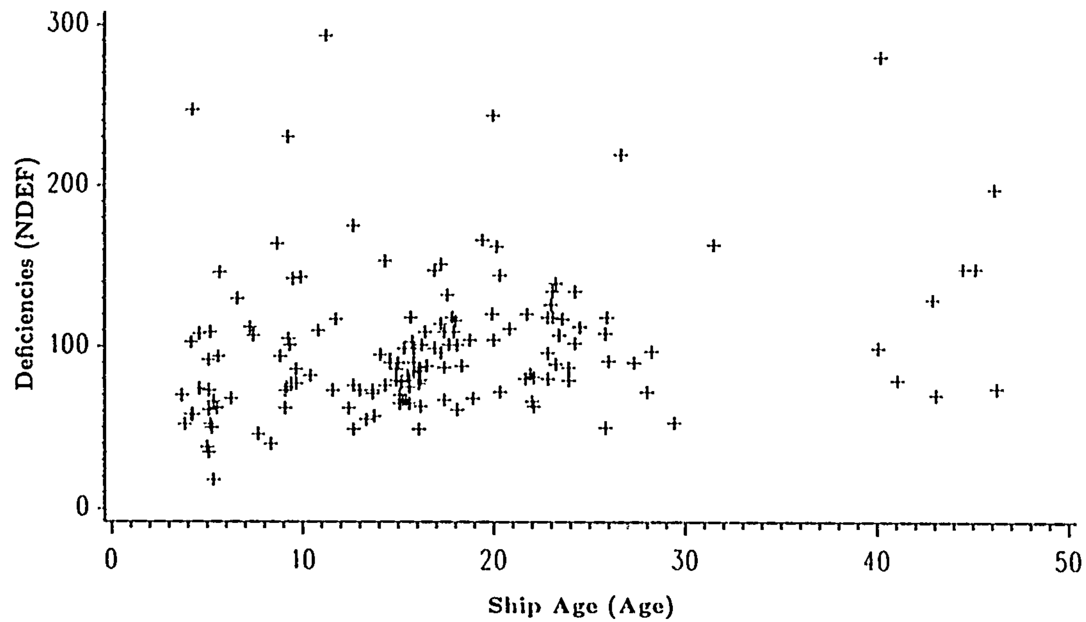

FIG. 4: NUMBER OF DEFICIENCIES BY YEARS SINCE COMMISSIONING

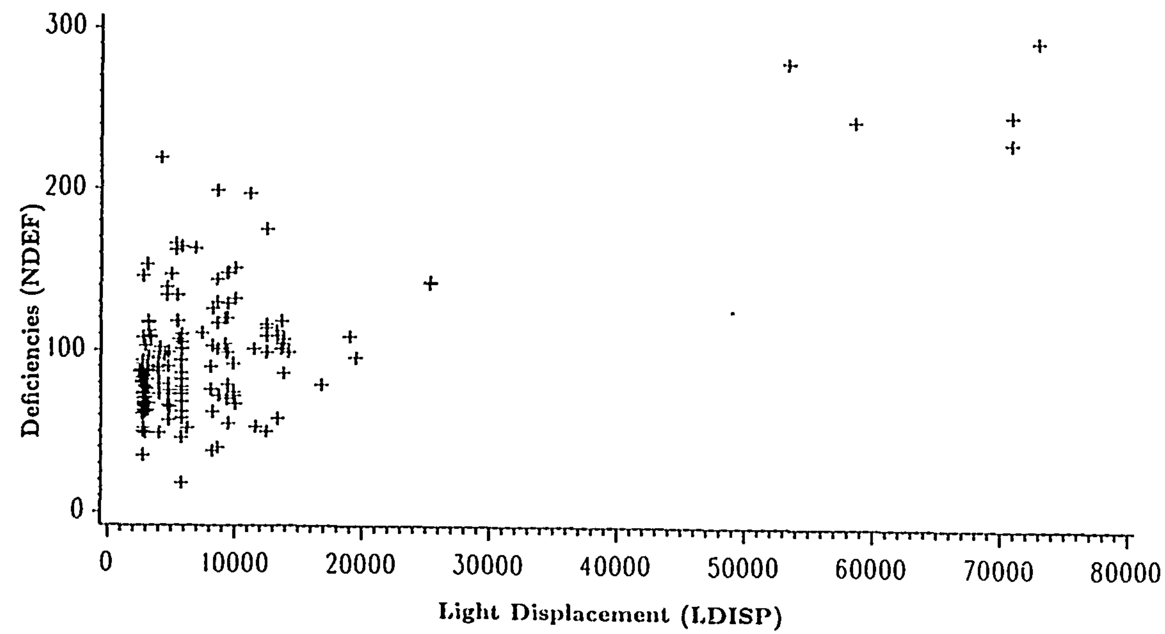

FIG. 5: NUMBER OF DEFICIENCIES BY LIGHT DISPLACEMENT

inspection (recall from table 3 that one of the other variables was associated with inspection year). Specifically, the following standardization was attempted:

$$NDEF^* = NDEF - [\hat{\beta}_0 + AGE\,\hat{\beta}_1 + LDISP\,\hat{\beta}_2 + (YEAR - 83)\,\hat{\beta}_3] \qquad (1)$$

where $\hat{\beta}_i$ is the ordinary least square (OLS) estimate of β_i.

If the effect of only ship age were being factored out, the above adjustment would correspond to drawing the "best-fitting" line through figure 4, and $NDEF^*$ would be the difference between this line and the actual number of deficiencies. Because ship age, light displacement, and inspection year are being adjusted, however, the adjustment is a little more complicated.

The estimates from equation 1 are given in table 4. Note that ship age, light displacement, and inspection year are all strongly positively associated with the number of deficiencies. The R^2 of .58 indicates that 58 percent of the total variation is explained by these three variables. Each additional year of ship age increases the predicted number of deficiencies by 1.12. Each additional 1,000 tons of light displacement increases the predicted number of deficiencies by 3. Whether or not this standardization is effective can be examined empirically. If it is effective, the standardized number of deficiencies should not vary much by ship type. A plot of the standardized deficiency counts by ship type is given in figure 6. The values of $NDEF^*$ tend to fall on both sides of the average value of zero for most ship types[2]. Although this standardization is imperfect, $NDEF^*$ should be adequate for exploratory purposes.

TABLE 4

OLS ESTIMATES FOR STANDARDIZATION

Effect	Estimate ($\hat{\beta}$)	t-statistic
INTERCEPT	33.42	—
AGE (years)	1.12	4.52[a]
LDISP (tons)	.003	13.28[a]
YEAR[b] - 83	10.81	4.32[a]

NOTES: Number of inspections = 155, R^2 = .58.

[a] Significant at the .01-percent level.

[b] Year of the inspection.

[2] An F-test of the assumption that the $NDEF^*$s do not vary has a value of 1.70 with 21 and 134 degrees of freedom, with an an associated p-value of .04.

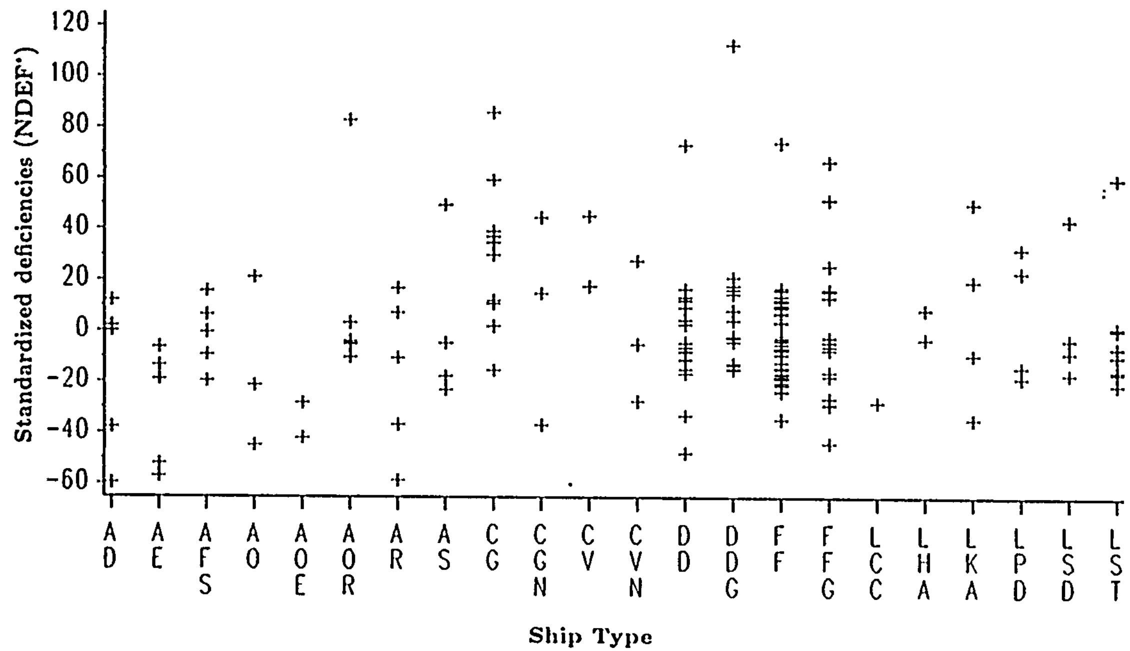

FIG. 6: STANDARDIZED DEFICIENCIES BY SHIP TYPE

With this standardized measure, the effect of EM manning can be assessed. As a first step, table 5 presents the correlations of $NDEF^*$ with the EM manning variables and the months since overhaul. All of the correlations are rather small and none are statistically significant. The table also indicates that the EM stability variables show an intuitively reasonable negative correlation, which means that the more stable the crew (the higher SAME3 or SAME6), the fewer the number of deficiencies. Figures 7 through 16 present the scatter plots of $NDEF^*$ against the variables in table 5. As suggested by that table, the figures are characterized by wide scatter, underscoring the small correlations in table 5. In short, there seems to be little statistical association between EM manning and the material condition of the EDS. Further analysis using more complicated models (see the appendix) do not change these conclusions.

TABLE 5

CORRELATIONS BETWEEN STANDARDIZED DEFICIENCIES AND OTHER VARIABLES

Variable	Correlation	Number of observations
OVHL (days)	-.13	153
AVGLOS (months)	-.05	151
E4-6	.10	153
E7-9	.05	151
HSGU	.03	151
HSGL	.06	151
NHSGL	-.07	151
PNEC	-.08	151
SAME3	-.06	151
SAME6	-.09	151

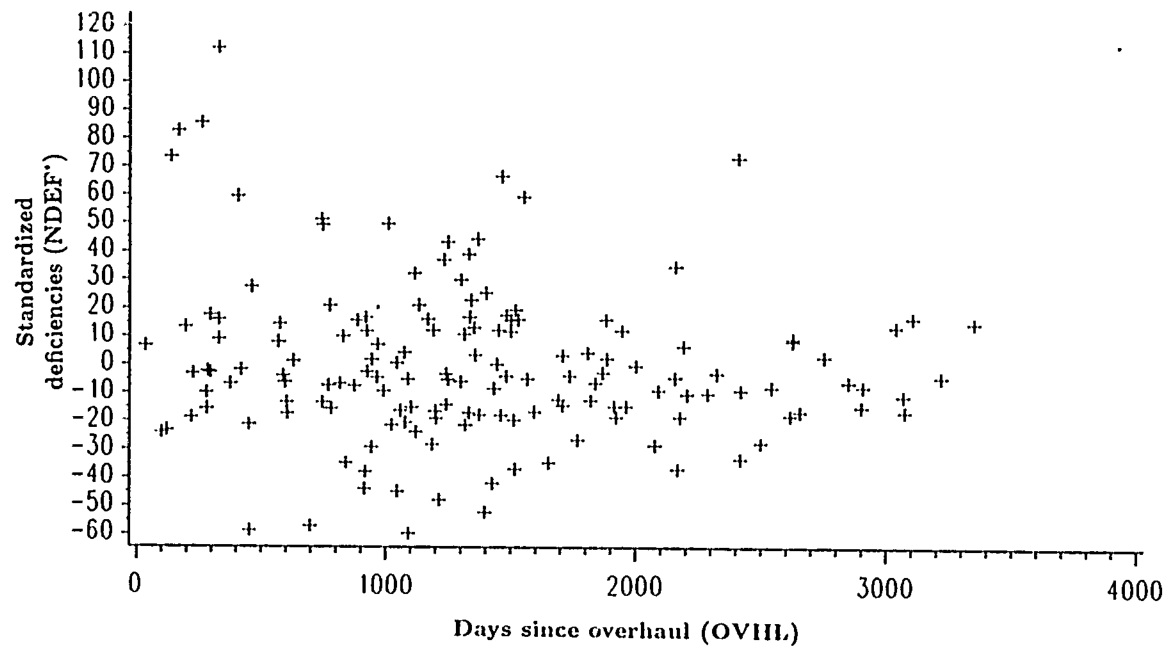

FIG. 7: STANDARDIZED DEFICIENCIES BY DAYS SINCE OVERHAUL

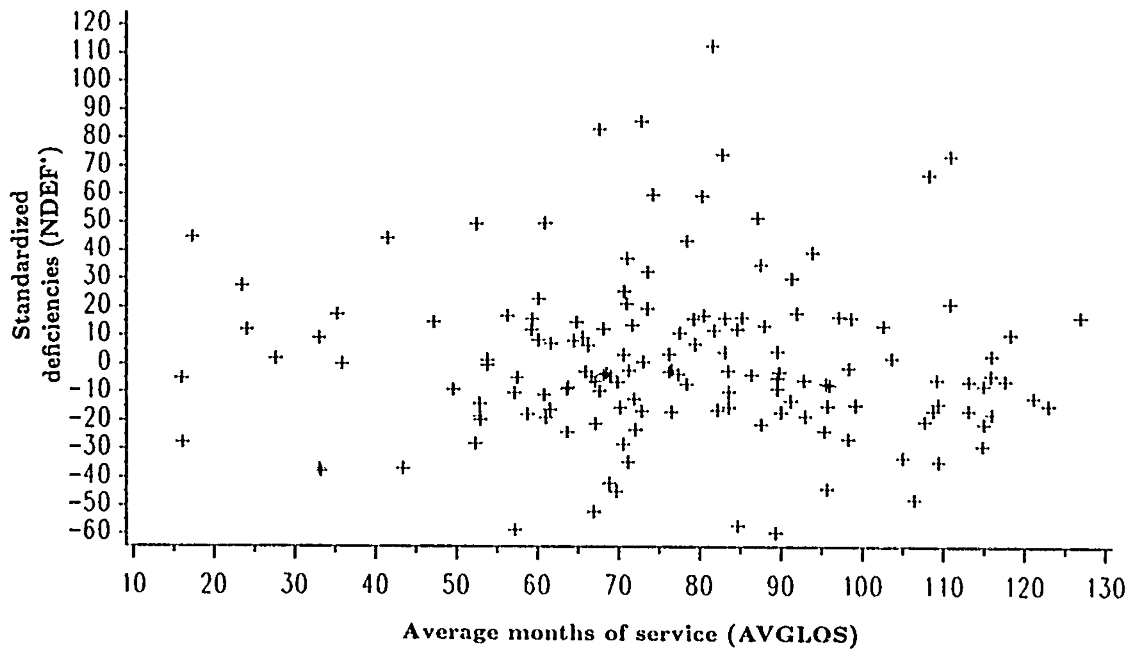

FIG. 8: STANDARDIZED DEFICIENCIES BY AVERAGE MONTHS OF SERVICE

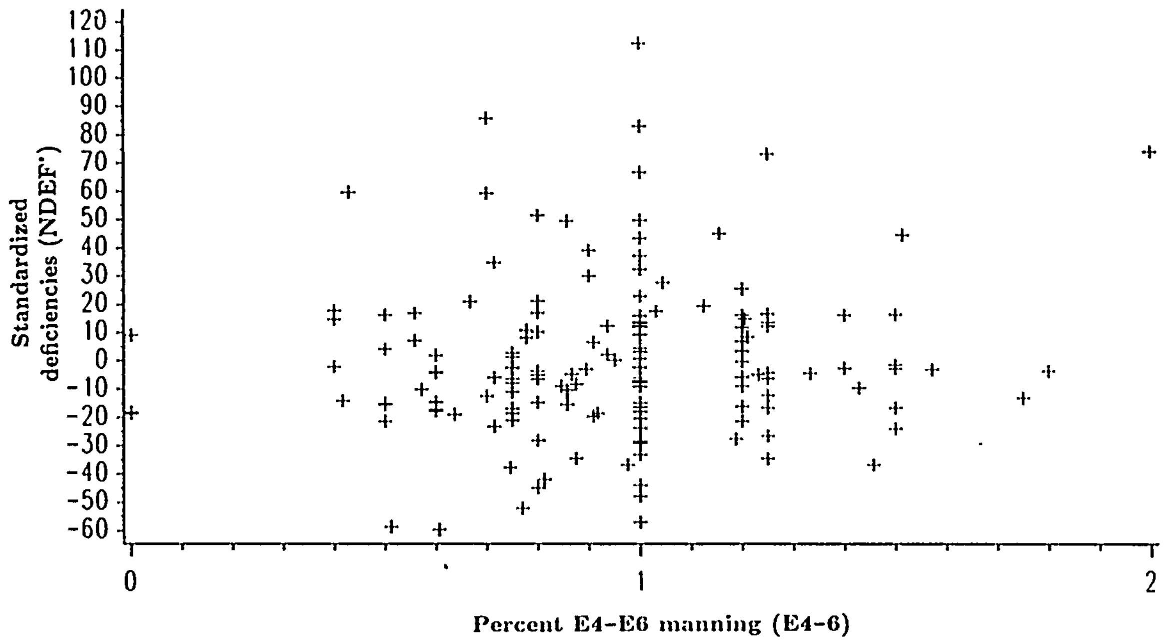

FIG. 9: STANDARDIZED DEFICIENCIES BY E4-E6 MANNING RELATIVE TO SMD REQUIREMENTS

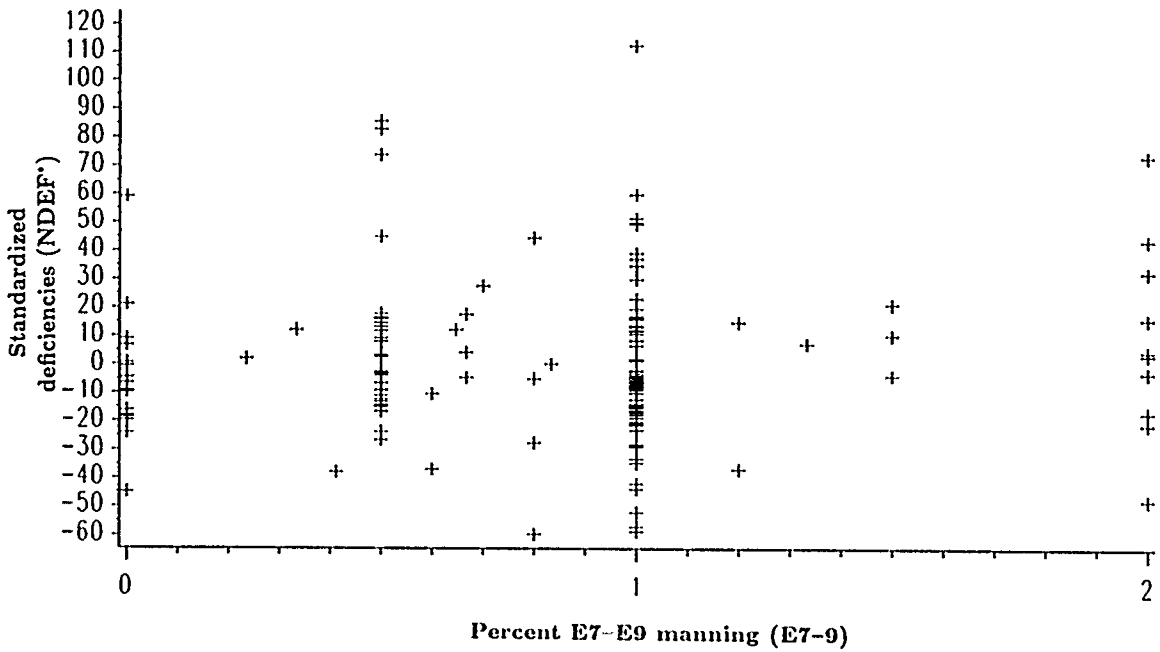

FIG. 10: STANDARDIZED DEFICIENCIES BY E7-E9 MANNING RELATIVE TO SMD REQUIREMENTS

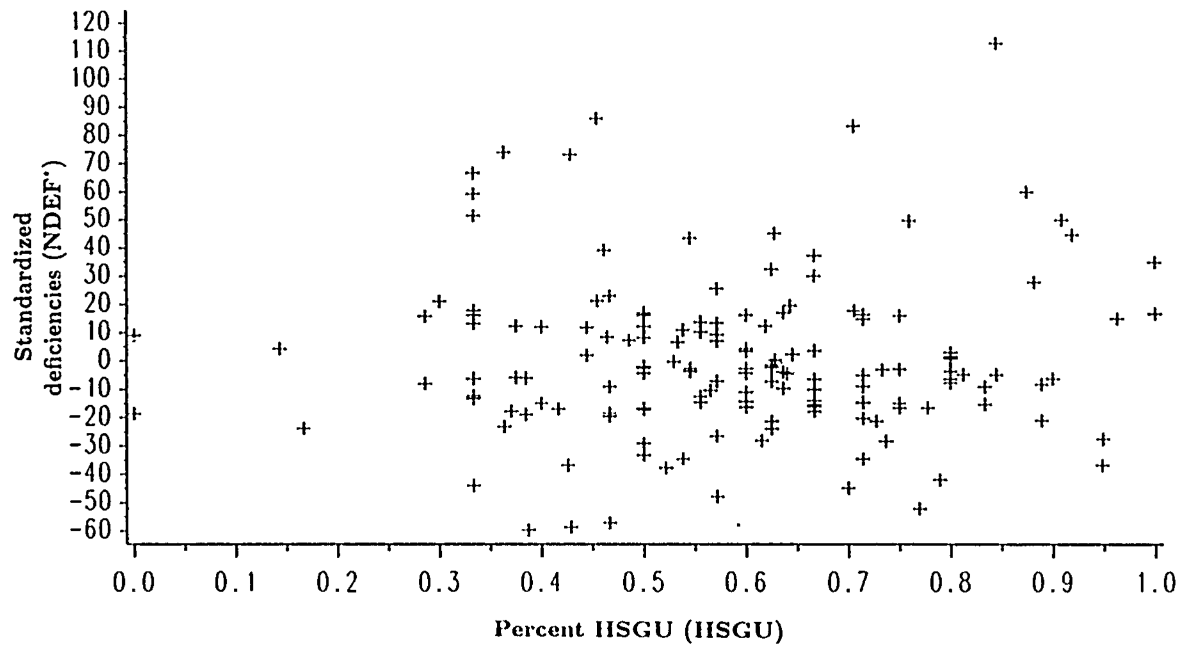

FIG. 11: STANDARDIZED DEFICIENCIES BY PERCENT OF EMs WITH HIGH SCHOOL DIPLOMAS AND IN THE UPPER MENTAL GROUP

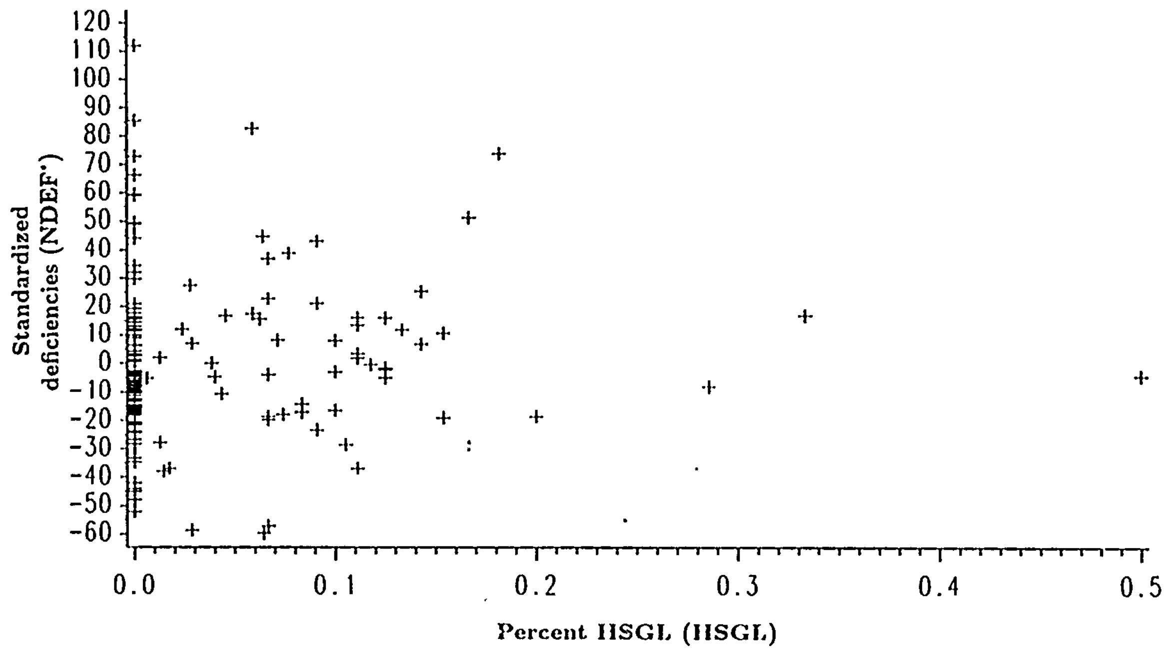

FIG. 12: STANDARDIZED DEFICIENCIES BY PERCENT OF EMs WITH HIGH SCHOOL DIPLOMAS AND IN THE LOWER MENTAL GROUP

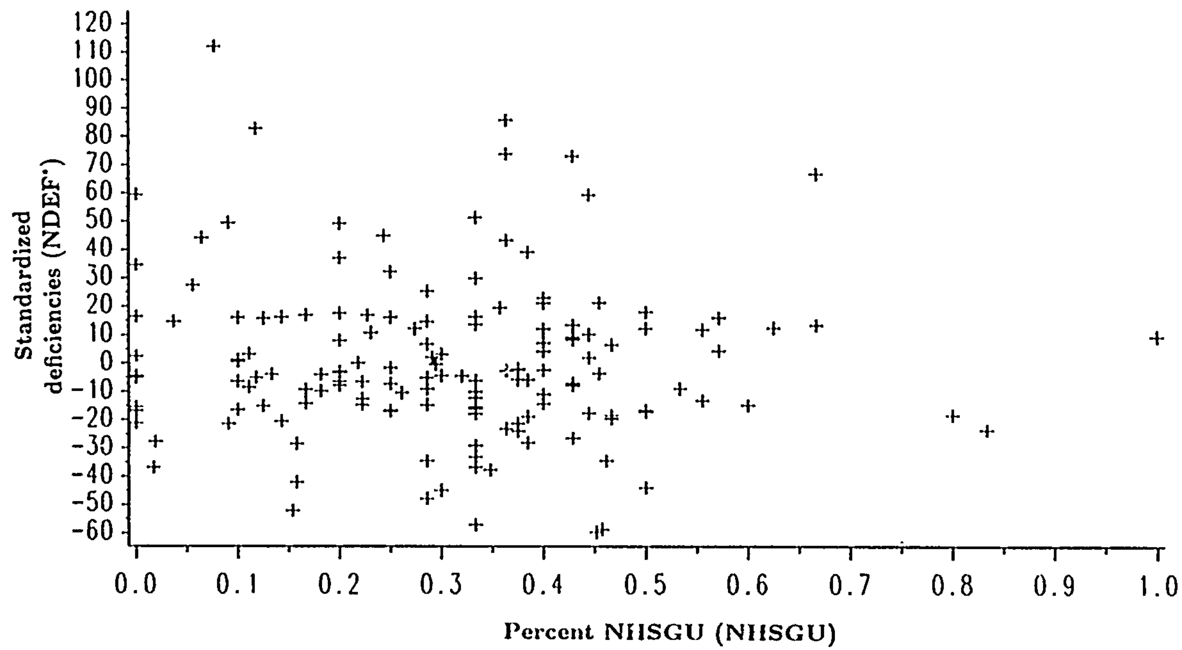

FIG. 13: STANDARDIZED DEFICIENCIES BY PERCENT OF EMs WITHOUT HIGH SCHOOL DIPLOMAS AND IN THE UPPER MENTAL GROUP

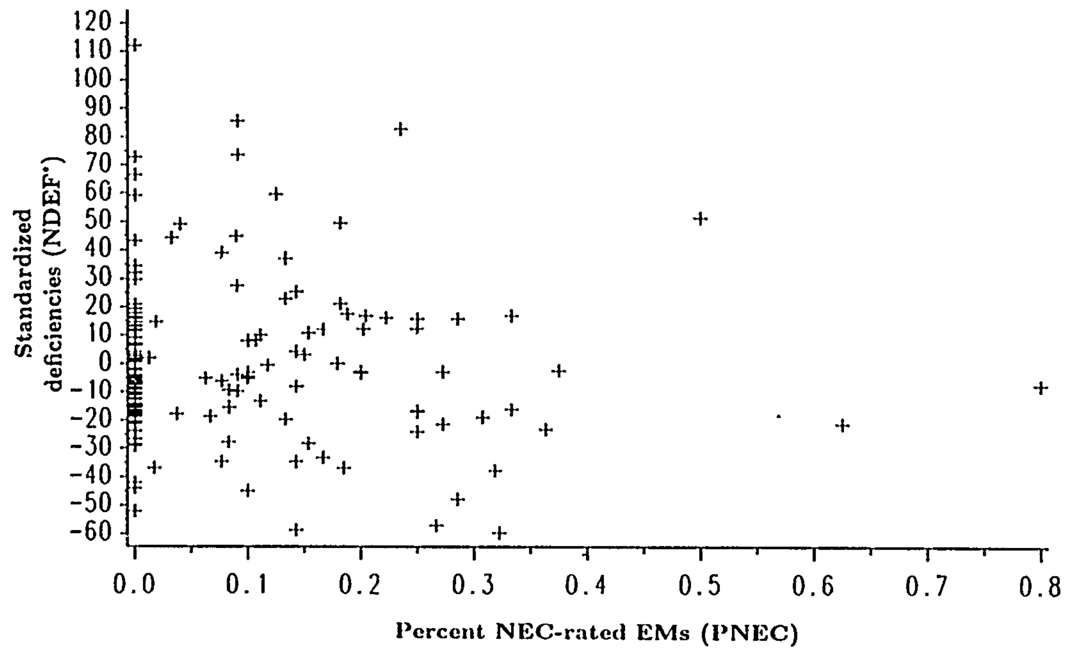

FIG. 14: STANDARDIZED DEFICIENCIES BY PERCENT OF EMs WITH NECs

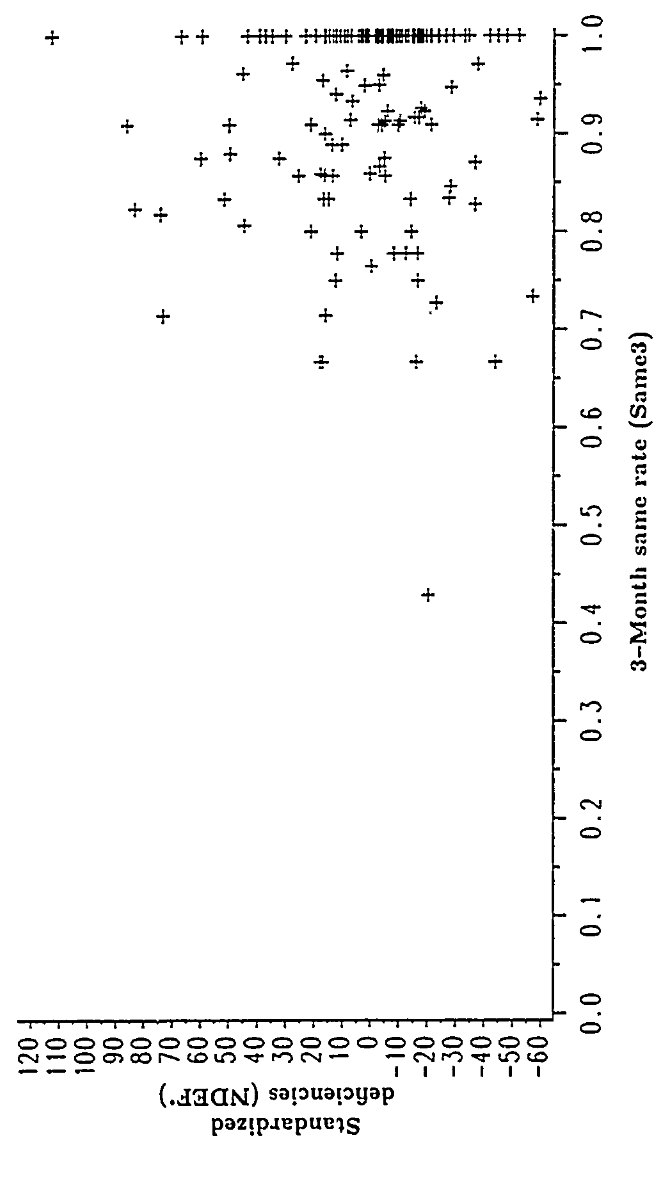

FIG. 15: STANDARDIZED DEFICIENCIES BY PERCENT EMs PRESENT THE QUARTER BEFORE THE INSPECTION AND TWO QUARTERS BEFORE THE INSPECTION

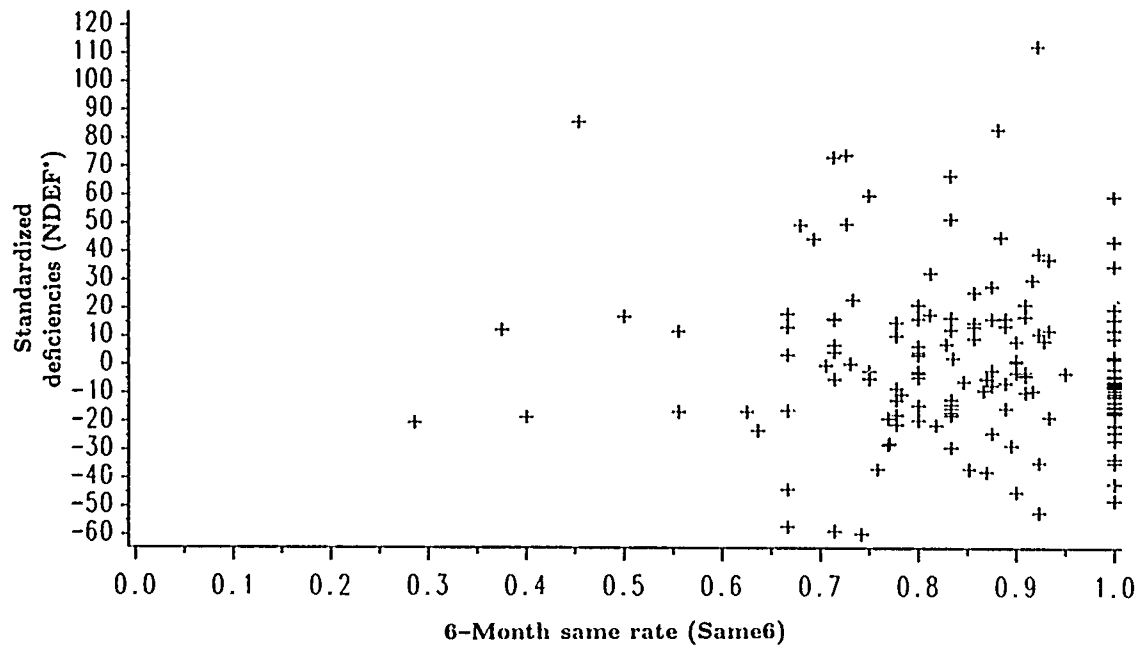

FIG. 16: STANDARDIZED DEFICIENCIES BY PERCENT EMs PRESENT THE QUARTER BEFORE THE INSPECTION AND THREE QUARTERS BEFORE THE INSPECTION

CONCLUSIONS

This research memorandum shows that ship age, light displacement, and the year of the inspection are all strongly related to the number of deficiencies in the EDS. The magnitude of these effects indicate that a one-year increase in a ship's age is associated with a predicted increase of 1.3 deficiencies. A 1,000-ton difference in light displacement is associated with a predicted increase of about 3 deficiencies. Older, heavier ships have more deficiencies than newer, lighter ones. Additionally, more deficiencies are reported in, say, 1986 than in 1984.

The aim of the study was to determine if a deterioration of the EDS is associated with ship age and if so, whether additional EM manning could offset this deterioration. Although clear evidence exists of the effect of ship age, no statistical evidence of an association between EM manning and the EDS condition was found, even though several statistical techniques were used.

This study does not prove that EMs have no effect on the EDS; it merely proves that a link cannot be found from the data in this analysis. The quality of EM manning may not be adequately captured by the variables in this study. In any event, knowledge that the EDS deteriorates with ship age may be useful to Naval planners in determining EM manning. Older ships are worse off in terms of the EDS. If planners are willing to assume that more EMs can help older ships, even though this cannot be statistically demonstrated, perhaps older ships should have more EMs.

REFERENCES

[1] CNA Research Memorandum 86-23, *Relating Personnel to the Material Condition of Surface Combatants*, by Philip M. Lurie, Jan 1986

[2] CNA Research Memorandum 87-85, *The Effects of Manning on the Material Condition of Surface Ships*, by Philip M. Lurie, Jun 1987

[3] Naval Sea Systems Command. S9234-AL-GTP-020/DD-963 PPM, *Propulsion Plant System for DD-963 Class Ships*, Volume 2

[4] Naval Sea Systems Command, NAVSEA 250-574-8, *Naval Vessel Register/Ships Data Book*, Volume 2, 1 Jul 1986

[5] CNA Research Memorandum 86-178, *Ship Employment Histories and Their Use*, by Karen N. Domabyl and Patricia A. Reslock, Jul 1986

APPENDIX

REGRESSION MODELS

APPENDIX

REGRESSION MODELS

In this appendix, a multiple regression model is specified to examine the joint effect of several variables on the number of deficiencies. With a multiple regression model, the effect of several variables can be assessed simultaneously. For simplicity, the effect of each of the EM variables on the number of deficiencies is examined separately in the main text. Most of the variables discussed in the main text are used, save for a few that were highly correlated with the others. Different models are estimated to examine the sensitivity of the results to the choice of model.

Specifically, the following form was assumed for the association between the manning, ship characteristic variables and the number of deficiencies[3]:

$$NDEF = X\beta + \epsilon \quad , \tag{A-1}$$

where

X = a vector of explanatory variables

β = a vector of regression parameters

ϵ = an error term with a normal distribution.

As indicated in the main text, AGE and LDISP may be used to standardize NDEF across ship type. Alternatively, dummy variables for ship type can be used. Table A-1 presents the estimates based on these two different specifications of X. In both, most of the EM manning variables are included.

[3] The square root of deficiencies was also considered to see if this transformation made the error term more normally distributed. The improvement with this transformation was negligible.

TABLE A-1

MULTIPLE REGRESSION PARAMETER ESTIMATES

	Standardization of NDEF			
	AGE and LDISP		Ship type dummies	
Effect	Estimate	t-stat.	Estimate	t-stat.
Intercept	60.51		100.22	
AGE	1.07	3.82[a]	—	
LDISP	.002	9.42[a]	—	
YEAR[b] - 83	11.35	3.40[a]	14.08	4.04[a]
E4-6	11.04	1.31	13.07	1.48
E7-9	6.10	1.12	8.28	1.47
OVHL	-.005	-1.44	-.007	-1.51
AVGLOS	-.11	-.81	-.28	-1.61
HSGU	-8.69	-.28	-10.18	-.32
HSGL	14.41	.34	20.94	.48
NHSGL	-21.22	-.70	-18.19	-.58
PNEC	-22.81	-1.12	-9.42	-.45
SAME6	-15.88	-.93	-29.77	-1.73

NOTE: Number of inspections = 148, R^2 = .58 using AGE and LDISP, .67 using ship type dummies.
[a] Significant at the .01 percent level.

The estimates in table A-1 confirm the analyses in the main text. Ship age, light displacement, and inspection year are all associated with the number of deficiencies. None of the EM manning variables has a statistically significant effect at the usual significance levels. Although the parameter estimates differ somewhat depending on which standardization is used, the substantive results are the same.

Other choices of X were also tried, notably, "dummy" variables for year of the inspection were included and separate equations were estimated for each ship type The results did not differ substantially from those of table A-1. In short, there is little consistent association between EM manning and the EDS.